AFIT/GLM/LSQ/92S-40

ESTIMATING THE OPERATING AND SUPPORT COST DIFFERENCE BETWEEN ROYAL AUSTRALIAN AIR FORCE C-130E AND C-130H HERCULES AIRCRAFT

THESIS

Terrence J. Sidey, Squadron Leader, RAAF

AFIT/GLM/LSQ/92S-40

The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

AFIT/GLM/LSQ/92S-40

ESTIMATING THE OPERATING AND SUPPORT COST DIFFERENCE BETWEEN ROYAL AUSTRALIAN AIR FORCE C-130E AND C-130H HERCULES AIRCRAFT

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

Terrence J. Sidey, Bachelor of Science, Graduate Diploma in Military Aviation

Squadron Leader, RAAF

September 1992

Preface

I undertook this research to help improve knowledge and understanding of aircraft operating and support (O&S) costing within the Royal Australian Air Force. At the beginning, my experience suggested that current RAAF O&S costing was rudimentary and that suitable RAAF O&S data would be difficult to obtain. Accordingly, I anticipated that I would have to place heavy reliance upon an analogous O&S costing system. I chose the USAF system for geographic reasons and because of the great experience that the USAF has in the field of weapon system costing. Research involving the RAAF C-130E and C-130H is timely because of the imminent replacement of the C-130E; possibly with a later model C-130.

I thank Dr.Roland Kankey and Lieutenant Commander Carl Schumaker, my thesis advisers, for their assistance. Squadron Leader Paul Pappas was my eyes and ears in Australia; without his help, this research could not have been completed. Steve Passage provided valuable assistance in introducing me to numerous costing people, who subsequently were a source of great help.

Most of all, I thank my wife Yvonne for her perseverance and help during the many trying months of this research. Jackie and Andrew, my children, were a source of joy also throughout. Thank you.

Terry Sidey

Table of Contents

Page

Page

Page

<u>List of Figures</u>

List of Tables

AFIT/GLM/LSQ /92S-40

Abstract

This research investigated the operating and support cost (O&S cost) of Royal Australian Air Force (RAAF) C-130E and C-130H aircraft. The purpose was twofold—provide information about the relative O&S cost of the RAAF's old and "new" C-130 aircraft; and increase knowledge and understanding of aircraft O&S costing within the RAAF.

Preliminary research indicated that RAAF O&S costing was rudimentary and that suitable RAAF O&S data would be difficult to obtain. Accordingly, an analogous O&S cost system—the USAF SABLE cost model and USAF C-130E/H aircraft—was used to estimate the RAAF C-130E/H cost difference. The foundation for this research is that RAAF and USAF C-130E/H aircraft, operations, and maintenance costs are not significantly different.

Based upon analogous costs of USAF C-130E and C-130H aircraft calculated using the SABLE model, this research concluded that the RAAF C-130E O&S cost is only about 2.3% greater than that of the RAAF C-130H. This accords with current, limited RAAF costing information and an earlier USAF study of increasing maintenance cost as an aircraft ages.

ESTIMATING THE OPERATING AND SUPPORT COST DIFFERENCE BETWEEN ROYAL AUSTRALIAN AIR FORCE C-130E AND C-130H HERCULES AIRCRAFT

I. Introduction

Thesis Overview

This thesis researches the operating and support cost (O&S cost) of Royal Australian Air Force (RAAF) C-130E and C-130H Hercules aircraft. O&S cost is a major component of the "total ownership cost", or life cycle cost (LCC), of an aircraft. This makes O&S cost an important economic and financial consideration (13:5). The O&S cost of the two C-130 models is compared because the RAAF is now investigating replacement of the relatively old C-130E, which is perceived to be more expensive to maintain and operate than a newer aircraft such as the C-130H (32).

Ideally, an O&S cost comparison could be accomplished simply by comparing the currently available O&S cost of each C-130 model. However in 1989, a thesis by a RAAF student at AFIT described significant shortcomings in the methodology used by the RAAF for calculating O&S cost (15:5). In addition, other sources have cast doubt upon the validity and usefulness of RAAF aircraft O&S costing (9:II; 14:2-7; 27). Accordingly, current RAAF O&S costing was not used as the basis for the cost comparison. Rather, another O&S costing methodology was developed for use with whatever RAAF costing data was available.

This thesis is organized into five chapters. Chapter I is an overview of the research. Several topics are introduced in Chapter 1 and then described more fully in Chapter II. Topics in Chapter I include: the research problem, the research objective, investigative questions, research assumptions, research scope and limitations, and anticipated benefits of this research.

The purpose of this thesis is to increase the RAAF's knowledge of aircraft O&S costing and to provide the RAAF with a better C-130E/H O&S costing method.

Background

Life Cycle Cost (LCC)—What Is It?. The US Department of Defense (USDOD) and the United States Air Force (USAF) employ several different descriptions of life cycle cost. One of the more authoritative descriptions is provided by the Cost Analysis Improvement Group (CAIG), which is part of the Office of the [US] Secretary of Defense.

> The life cycle of a weapon system begins with the determination of a mission requirement and continues through the engineering and manufacturing development, production and deployment, and operations and support phases to the eventual disposal or demilitarization of the system by the government. For purposes of cost estimating, life cycle costs typically are divided into four components: research and development, investment, operating and support, and disposal . . . Program phases also may overlap considerably. (25:2-1 to 2-2)

Life cycle costing is sometimes referred to as a "cradle to the grave" approach. This recognizes that decisions made early can greatly influence costs throughout the life of a system (25:2-7; 13:12). Note that O&S costs are included in the CAIG definition of LCC.

LCC—Why Is It Important? Life cycle cost is important because "All other factors remaining equal, people will [best] meet their needs by procuring goods and services that offer the highest value/cost ratio" (13:5). One author writes that "more than half of the projected life-cycle cost is committed by the end of the system planning and conceptual design" (13:12). Another writes about a study that concluded that "the operating costs of a hospital in its first three to five years of existence often exceeded the entire cost of construction" (11:1-1 to 1-3). Such revelations show that the total (lifetime) cost of a system is more important than segments only, such as capital cost.

LCC and Cost-Effectiveness. LCC plays an important role in cost effectiveness analysis, in which the following types of attributes are considered: ease of manufacture, availability, reliability, performance, supportability, and manability. "In the fixed-cost approach, the basis for selection is the amount of effectiveness obtained at a given cost; in the fixed-effectiveness approach it is the cost incurred to obtain a given level of effectiveness" (13:114). For example, ordering of competing systems' attributes simplifies rejection of unsuitable alternatives. The remaining systems can then be analyzed according to (life cycle) cost and effectiveness.

Operating and Support Cost (O&S Cost). O&S cost is a component of LCC. It is a major consideration for two reasons. First, it is a current and recurring cost to the operator. Second, "Experience has indicated that a large proportion of the total cost for many systems is the direct result of activities associated with their operation and support" (13:13). O&S cost also has several descriptions; again the CAIG description is given.

> [Operations and support cost] Includes all costs of operating, maintaining, and supporting a fielded system. [It] Encompasses costs for personnel; consumable and repairable materials; organizational, intermediate and depot maintenance; facilities; and sustaining investment. The O&S phase overlaps with the Production and Deployment phase. O&S costs are incurred in preparation for and after a system's fielding and continue through the end of the system's useful life. (25:2-3 to 2-4)

For this research, no RAAF C-130 aircraft is likely to be affected by either production and deployment, or disposal phase costs. The newest RAAF C-130 was manufactured in 1979 and the earliest planned C-130 withdrawal date is 1997 (28; 24).

Costing Within the RAAF. Application of LCC and O&S costing was found to be still in its infancy in the RAAF. However, stringent budgets are forcing more attention on weapons' system cost and LCC [and its components] has now been formally adopted by the Australian Department of Defense as a logistics principle (1).

The C-130E Refurbishment/Replacement Investigation. The RAAF operates 12 C-130E and 12 C-130H Hercules aircraft. The C-130E fleet is about 27 years old (manufactured in 1965/66) while the C-130H fleet is about 14 years old (manufactured in 1978/79) (28). The perceived increasing cost of C-130E maintenance and the relatively old age of the aircraft systems are two reasons that have prompted the RAAF to investigate C-130E refurbishment/replacement (32:1). Several investigations have been conducted into various aspects of C-130E refurbishment, but inadequate O&S cost information is hindering these investigations (32).

RAAF Cost Data. RAAF cost data is not collected comprehensively, and the data that is collected is often aggregated. This general unavailability of detailed RAAF aircraft O&S cost data is revealed in a report about RAAF P-3C cost

effectiveness (14). Other research by an officer at RAAF headquarters in Australia in 1992 confirms that a similar data gathering problem exists for the C-130 fleet (27). Lack of suitable RAAF cost data was the primary obstacle to this research.

The Bathtub Curve Effect. When this research was begun, RAAF C-130E O&S cost was anticipated to be significantly greater than that of the RAAF C-130H.

1) The C-130E and C-130H are very similar aircraft, in terms of physical and operational characteristics. However, the RAAF C-130E is about thirteen years older than the RAAF C-130H (20).

2) Any major O&S cost difference would probably result from the different age of each aircraft.

3) The "bathtub effect" predicts that a system nearing the end of its useful life will incur increasing maintenance costs as system reliability decreases (caused by things such as: fatigue damage, age deterioration, and system obsolescence) (6:5-36 to 5-44; 13:354-355).

The bathtub curve effect derives its name from a graph of system failure rate plotted against system age, as illustrated in Figure 1.1. The figure illustrates how the failure rate of a system is believed to: start high (due to "bugs") as the new system is introduced into service; then become relatively low for the majority of the system's life; and then increase as the system achieves old age and begins to "wear out". The cost of unscheduled maintenance varies with the failure rate (6:5-36 to 5-44; 13:354-355). Interestingly, the increasing maintenance cost predicted by the Bathtub Curve Effect is challenged in a 1984 USAF study. "The study concludes that there is little evidence that maintenance costs increase dramatically as an aircraft ages" (10:ii).

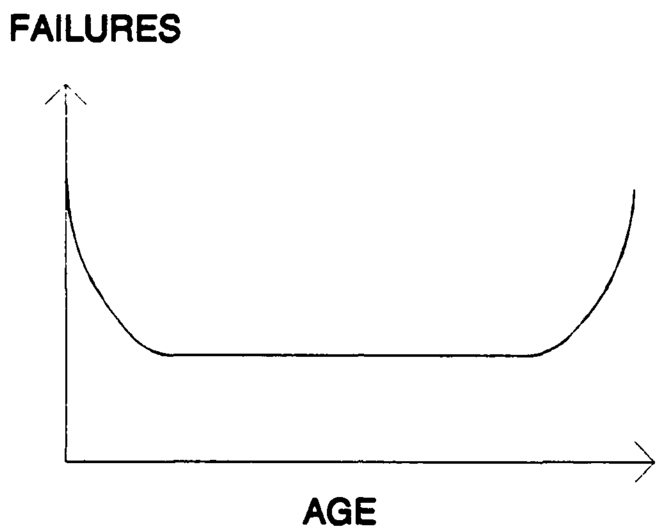

Figure 1.1 The Bathtub Curve Effect

Research Problem

The RAAF needs information about the relative O&S cost of its C-130E and C-130H aircraft to facilitate better decisions about fleet refurbishment, modification, and replacement. The costing that is done now is mainly for cost recovery and the information is too aggregated for other purposes.

Research Objective

The objective of this research is to estimate the O&S cost difference between RAAF C-130E and C-130H Hercules aircraft. In the process, an O&S cost model will be selected for research cost calculations and for possible future use by the RAAF. This will provide the RAAF with better O&S cost information and a better method for calculating C-130 O&S cost.

Investigative Questions

This thesis addressed the following investigative questions (IQ's):

IQ1. What is O&S cost?

IQ2. How is O&S cost determined?

IQ3. What data is needed to determine O&S cost?

IQ4. What RAAF cost data is known?

IQ5. What method is most suitable for estimating RAAF C-130 O&S cost?

IQ6. What is the O&S cost of RAAF C-130E and C-130H aircraft?

IQ7. What is the O&S cost difference between RAAF C-130E and C-130H aircraft?

IQ8. How accurate is the calculated RAAF C-130E/H O&S cost difference?

Definitions

Appendix A contains a glossary of definitions used in this thesis.

Research Assumptions

This thesis builds upon the following research assumptions (RA's):

RA1. Differences between RAAF and USAF C-130E/H aircraft, operations, or maintenance do not invalidate the use of USAF O&S cost methods for the determination of RAAF C-130E/H O&S costs.

RA2. USAF O&S costing methodology is correct.

RA3. USAF O&S cost factors used in this thesis are accurate.

Research Scope and Limitations

This research estimates the difference in O&S cost between the 12 RAAF C-130E and 12 RAAF C-130H aircraft based at Richmond, New South Wales, Australia.

Only active duty USAF C-130E and C-130H aircraft were costed.

Validity of USAF costing information and models was not thoroughly researched.

The search for O&S costing information was limited to the USDOD and the ADOD.

Primary data collection was not done. All research calculations utilize secondary data.

Benefits of this Research

This research is intended to provide the RAAF with improved O&S cost information and a better method for calculating C-130 O&S cost. The research may also benefit the current investigation into replacement of the C-130E by providing an approximate comparison of C-130E and C-130H O&S costs, and by increasing peoples' awareness of LCC considerations. Finally, a better starting point for future investigations into RAAF O&S costing is established.

Thesis Organization

This thesis is organized into five chapters:

1) Chapter I is an overview of this research. Many subjects are introduced, and then developed more fully in Chapter II. Other topics in Chapter I include the research problem, the research objective, investigative questions, research assumptions, research scope and limitations, and the anticipated benefits of the research.

2) Chapter II contains a literature review and other background information.

3) Chapter III describes the research methodology.

4) Chapter IV contains O&S calculations, including the RAAF C-130E/H cost comparison calculations. In Chapter IV, the O&S cost difference between RAAF C-130E and C-130H Hercules aircraft is estimated.

5) Chapter V describes thesis conclusions and recommendations.

II. Background Information

Overview

The information contained in Chapter II provides the foundation for the calculations and analysis in subsequent chapters. In particular, this chapter attempts to answer the following investigative questions:

IQ1. What is O&S cost?

IQ2. How is O&S cost determined?

IQ3. What data is required in order to determine O&S cost?

IQ4. What RAAF cost data is known?

IQ5. What O&S cost determination method is most suitable for determining RAAF C-130 O&S cost?

USDOD documents provide the bulk of the information about O&S costing for this research. Australian data is obtained from several sources, but primarily from the Directorate of Resource Analysis (DRA-AF) in the ADOD. A major constraining factor was the ADOD's limited breadth of experience in aircraft costing, coupled with a limited data base.

The C-130E/H

The C-130 is a high-wing, four engine, turbo-prop, tactical transport aircraft. It is designed for airtransport of troops or cargo from unpaved airfields, over distances of several thousand miles. The aircraft can also be configured for search and rescue, and medical evacuation missions (30:1-1; 31:1-1). The main strengths of the aircraft are

its versatility, low reliance on ground support, and ruggedness. The C-130 has been built since the 1950's; and the current basic production model is the C-130H (22).

The C-130E and C-130H are very similar aircraft outwardly; but they differ significantly in the areas of: wing structure, engines, airframe systems (such as air conditioning, auxiliary power unit, brakes), landing gear, corrosion resistance, electrical systems, fuel system, and avionics (30:Section 1; 31:Section 1; 22:5-11). The C-130H generally has more modern systems than the C-130E. The C-130E is fitted with the 3,755 ESHP (Equivalent Shaft Horsepower) Allison T56-A-7 engine, and the C-130H is fitted with the 4,910 ESHP Allsion T56-A-15 engine (30:1-1; 31:1-1). "Design and material changes in the basic aircraft structure . . . have improved fatigue life and reduced structural maintenance requirements" (22:5). Accordingly, any differences in the O&S cost of each aircraft will most probably be the result of inherent model differences and the age differential.

The C-130 in the RAAF

The RAAF operates 12 C-130E and 12 C-130H Hercules aircraft. All aircraft are based at Richmond, New South Wales, Australia. The aircraft are used for a variety of roles including: strategic transport (long-range operations), tactical transport (low level operations, and operations involving substandard airfields—C-130H only), search and rescue, and aeromedical evacuation. The primary role of the C-130E is strategic transport, and the primary role of the C-130H is tactical transport. Most maintenance is common and is performed at Richmond; however some is done in New Zealand (28). Common operating policies are employed for each model. However, a

notable operating distinction is that the C-130E cruise speed is 280KTAS (knots—true air speed) whereas the C-130H cruise speed is 300KTAS (29).

The C-130 in the USAF

The USAF operates about 150 C-130E and 50 C-130H aircraft on active duty [only active duty USAF C-130 aircraft are costed in this thesis] (18). In 1989 Green found that "The USAF does not divide the roles of the Hercules aircraft in the same manner as the RAAF. All operational C-130 squadrons in the USAF can be involved in a combination of tactical and long range transport missions" (15:3). This blending of missions would serve to reduce O&S cost differences that are a function of operational employment policies. A comparison of USAF C-130E and C-130H O&S costs would therefore be more representative of inherent differences between the two models.

What is Life Cycle Costing?

"All other factors remaining equal, people will [best] meet their needs by procuring goods and services that offer the highest value/cost ratio" (13:5). This truism belies the difficulties inherent in trying to determine the cost of some goods or services. This is particularly so in the case of aircraft, which have many complicated systems and a long life. Life cycle costing attempts to formalize this costing process.

The Life Cycle. The life cycle of a system extends beyond the life of the system itself. It includes all processes beginning with the initial system concept and ending with final system disposal. This period cannot reasonably be shortened

because so many decisions made outside of the life of the system itself affect overall system cost. "More than half of the projected life-cycle cost is committed by the end of the system planning and conceptual design" (13:12). All of the LCC definitions described in this research use this "cradle to the grave" concept of the life cycle.

Life Cycle Cost. Fabrycky and Blanchard describe life cycle cost as the total of those system costs which fall into the following activity categories: research and development, production and construction, operation and support, and retirement and disposal (13:125-126). The AFLC Cost Analysis Handbook defines LCC as:

> The total cost to the Government of acquisition and ownership of the system over its full life. It includes the cost of development, acquisition, operation, support, and where applicable, disposal. (6:5-23)

This is very similar to the definition used by the Cost Analysis Improvement Group (25), which was cited in Chapter I. "[Various] directives and instructions make the CAIG responsible for establishing criteria, standards, procedures, and documentation requirements for cost estimates. After reviewing a cost estimate prepared by a DOD component, the CAIG must submit a report to the DAB [Defense Acquisition Board—the mechanism for obtaining DOD Secretarial costing decisions]" (25:1-2; 6:14-7). The CAIG and AFLC description of LCC is adopted for this research. Figure 2.1 illustrates a typical LCC profile.

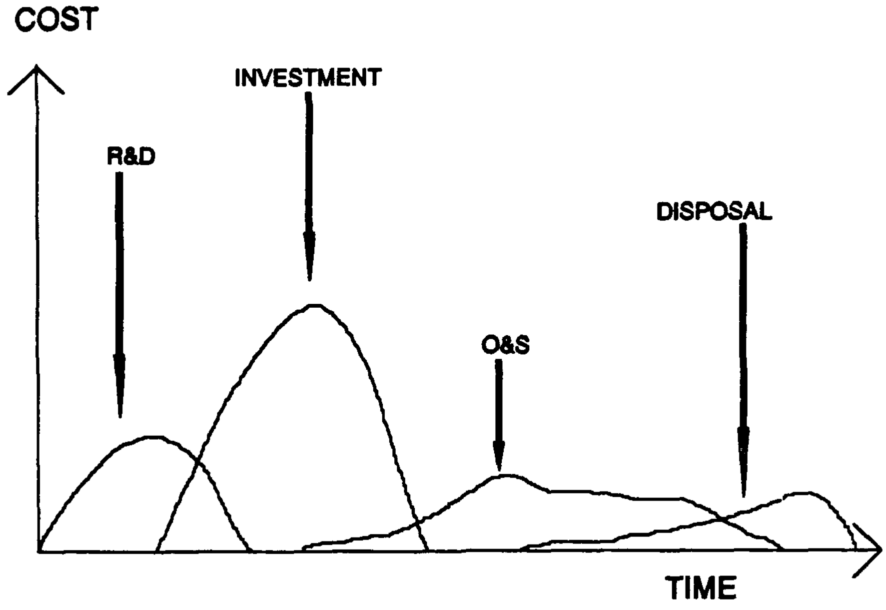

Figure 2.1 Typical Life Cycle Cost Profile (13:138)

O&S Costing

> System operations and support costs, also known as ownership costs, are the fixed and variable costs of personnel, material, facilities, and other items needed largely for the peacetime operation, maintenance, and support of a system during activation, steady state operation, and disposal. For cost estimating purposes, the convention has been to include only those costs associated with system activation and steady-state operation . . . Specific cost elements included in the O&S cost of a system vary with the system type and the guidance for particular estimates. (6:17-3,4)

Two points raised in the AFLC Cost Analysis Handbook are significant to this research about O&S costing: only certain, specific costs are considered; and costing methodology varies among systems. This suggests that an O&S costing must be tailored to each specific application.

Cost Categories. O&S writings list similar main cost categories but, often, different sub-categories. The CAIG guide lists mission personnel, unit-level consumption, intermediate maintenance, depot maintenance, contractor support, sustaining support, and indirect support as main cost categories (25:B-1). A listing of several main cost categories is presented for comparison in Appendix G. A common theme is that costs are continually broken down until the desired level of differentiation is reached, or until data collecting or cost allocating becomes impractical.

Fixed and Variable Costs. The distinction between fixed and variable cost was an important consideration in Green's thesis: "The impact of different cruise speeds on aircraft operating costs could then be derived in terms of the effect on variable operating costs" (15:28). Fabrycky defines a fixed cost as one "involved in a going activity whose total will remain relatively constant throughout the range of operational activity" and a variable cost as one that will "vary in some relationship to the level of operational activity" (13:23). Others give similar definitions (19:944, 949; 23:969). This distinction questions the current RAAF policy of treating all C-130 maintenance as a fixed cost, independent of flying hours (15:40; 9:Annex E).

Summary. O&S costs are broken down into components as dictated by the needs of each situation; however, data collection and cost allocation difficulties may limit the degree of cost breakdown. Accordingly, each O&S costing is similar but different.

The Purpose of Cost Estimating

Cost estimating has two general purposes:

1) Comparative studies which serve as a discriminator that assists management in evaluating and selecting among alternative solutions that are available to satisfy a given requirement or problem

2) Budget formulation which supports the budget process by providing an estimate of funds that will be required to efficiently execute a program or project. (8:10-6)

In the case of comparative studies, only relevant costs need be considered. "Relevant costs are defined as those which are likely to be different among the alternatives considered as well as those which may be required by the governing directive of the comparative study. If one or more elements of cost are equal for all competing alternatives, then their value is irrelevant with regard to selecting an alternative [this type of cost is called a 'common cost']" (8:10-6 to 10-7).

Developing a Cost Breakdown Structure

> [A cost breakdown structure (CBS) is] a logical subdivision of cost by functional activity area, major element of a system, and/or more discrete classes of common or like items . . . The CBS constitutes the framework for defining life cycle costs [and O&S costs] and provides the communications link for cost reporting, analysis, and ultimate cost control. (13:28,132)

Mary Eddins-Earles writes that a CBS is "an ordered breakdown of the elements of cost estimated to arrive at a total life cycle cost" (11:2-1). Cost breakdown structure is also known as cost element structure (25:3-9; 6:17-34; 7:10-13). As the name implies, the structure is typically hierarchical. Four cost breakdown structures are now described.

A Generic O&S Cost Breakdown Structure. Fabrycky and Blanchard give a generic operation and maintenance support cost breakdown structure in their book on LCC and economic analysis:

1) system/product life-cycle management
2) system/product operations
3) system/product distribution
4) system/product maintenance
5) inventory—spares and material support
6) operator and maintenance training
7) technical data
8) system/product modifications (13:29)

Fabrycky and Blanchard believe that a CBS should exhibit the following characteristics:

1) all relevant LCC costs are included
2) costs are broken down to the level required to meet the costing objective
3) cost categories are well defined and understood
4) categories are identified with specific areas of interest
5) the categories used should facilitate analysis of specific areas of interest
6) the CBS should be compatible with other relevant systems, policies, documentation, etc. (13:29-30)

The CAIG Cost Breakdown Structure. The CAIG supplies a generic, and slightly more detailed, CBS:

1) mission personnel:

   a) operations

   b) maintenance

   c) other mission personnel

2) unit level consumption:

   a) POL/energy consumption

   b) consumable material/repair parts

   c) depot-level repairables

   d) training munitions/expendable stores

   e) other

3) intermediate maintenance (external to unit):

   a) maintenance

   b) consumable material/repair parts

   c) other

4) depot maintenance:

   a) overhaul/rework

   b) other

5) contractor support:

   a) interim contractor support

   b) contractor logistics support

   c) other

6) sustaining support:

   a) support equipment replacement

b) modification kit procurement/installation

c) other recurring investment

d) sustaining engineering support

e) software maintenance support

f) simulator operations

g) other

7) indirect support:

a) personnel support

b) installation support. (25:4-2)

The CAIG advises that the aforementioned elements may need to be expanded into increased detail to facilitate auditing and to allow other parties to replicate the cost estimation (25:4-3).

The USAF SABLE Cost Breakdown Structure. SABLE is a USAF O&S cost model (described in more detail later) that uses the following cost categories for the C-130E:

1) aviation fuel

2) depot maintenance

3) consumable supplies

4) depot level repairables

5) replacement GSE (ground support equipment)

6) military pay

7) civilian pay

8) installation support—non-pay

9) PCS-military (permanent change of station)

10) training munitions

11) class IV modification kits

12) class IV modification installation

13) medical--non-pay

14) personnel acquisition and training. (33)

This CBS seems to accord with Fabrycky and Blanchard's advice to break down costs to the level required to meet the costing objective. As explained later, SABLE is designed to provide the Air Staff with a tool to cost force structure changes quickly and accurately.

The RAAF Cost Breakdown Structure. The RAAF generic cost breakdown structure is:

1) POL (petrol, oils, and lubricants)

2) replacement spare parts

3) contract servicing

4) in-house servicing

5) crew costs

6) on-costs (overhead)

7) capital costs (a depreciation allowance). (9:Annex E)

For a functioning CBS, the RAAF structure is notable for its brevity.

The book Factors, Formulas, and Structures for Life Cycle Costing contains a large number of CBS's that span a wide variety of systems, using organizations, and purposes (11:Section 2). Appendix B describes the RAAF/DRA-AF CBS (referred to

as a flying hour rate summary) in more detail, while Appendix C lists the Fabrycky/Blanchard, CAIG, SABLE, and RAAF/DRA-AF CBS for easier comparison.

What Level of Detail?

In a cost estimation, the required degree of data disaggregation is influenced by the purpose of the cost estimation and the nature of the data that is available. Excessive data aggregation can emasculate a costing that is intended to compare the cost of very similar systems. The level of detail, risk, and uncertainty are closely related. As elements are aggregated, risk and uncertainty increase (8:10-9).

Risk and Uncertainty

The objective of this research is to estimate the O&S cost difference between RAAF C-130E and C-130H Hercules aircraft. With perfect knowledge, the estimate would become a mere calculation and the cost difference would be known with certainty. However, when cost elements are known only approximately or not at all, estimation is required and an associated confidence indication is desirable. Risk and (un)certainty techniques provide one method for dealing with imperfect knowledge (6:14-44 to 14-51; 8:10-24; 13:95-116).

Risk refers to the probability of an outcome with a known probability of occurrence distribution. For example, the risk (or probability) of rolling a "1" on a six-sided die is "1/6", ceteris paribus (8:10-24). Uncertainty refers to the situation in which the outcome is subject to an unknown probability distribution. "The difference between the actual and estimated cost is called error, and is considered by most

experts to be more a function of uncertainty than risk" (8:10-24). Several approaches to treating risk and uncertainty are now described.

Decisions Under Risk. "Decision making under risk occurs when the decision maker does not suppress acknowledged ignorance . . . but makes it explicit through the assignment of probabilities. Such probabilities may be based on experimental evidence, expert opinion, subjective judgement, or a combination of these" (13:102). For example, in subjective estimator judgement an expert will revise an estimate to produce a final figure that "explicitly recognizes the existence of risk and uncertainty" (8:10:26). This method requires the assistance of an experienced cost analyst—the expert. In summary, risk can be dealt with objectively through the assignment of probabilities.

Decisions Under Uncertainty. "It may be inappropriate or impossible to assign probabilities . . . for a given decision situation. Often, no meaningful data are available from which probabilities may be developed. In other instances the decision maker may be unwilling to assign a subjective probability (13:106). Lack of meaningful data suggests that uncertainty analysis is appropriate. Fabrycky and others describe several tools for dealing with uncertainty.

1) Sensitivity Analysis. In sensitivity analysis, each variable in turn is varied while the others are held constant. This reveals the variable(s) with the greatest influence on the estimate and facilitates the focussing of error reduction efforts (6:14-45,46; 8:10-27). Sensitivity analysis may be appropriate to this research.

2) High/Low Analysis. In high/low analysis, upper and lower bounds are specified for each variable. This enables the calculation of highest, lowest, and mid-range values for the estimate. The shortcoming with this method is its failure to associate probability with any of the estimates, which can vary considerably (8:10-27; 13:107). This method also has relevance to this research.

3) Prediction Intervals. Prediction intervals are pre-determined ranges of the desired value. They are applicable when statistical analysis is used to produce estimates. This is a more rigorous method than those previously described, but is not likely to be relevant to this research because of the lack of data available for analysis (6:14-48; 8:10-27).

Conclusion. Risk analysis is appropriate when the amount of data available permits some degree of probability assignment; either experimentally, or subjectively. However, the paucity of RAAF O&S cost data precludes risk analysis. Sensitivity analysis might help to reveal cost drivers; however, this does not contribute to the objective of this thesis. Prediction interval analysis requires appropriate data, which is lacking. High/low analysis requires the nomination of appropriate upper and lower input variable values. High/low analysis is therefore practical and might help to establish bounds for the cost difference estimate.

Time Phasing the Estimate

Three choices are available for time-phasing the estimate: base-year dollars, constant-year dollars, and then-year dollars.

1) Base-Year Dollars. Dollars expressed in their value at the time of the specified base year of the program, as if they were all expended during that year.

2) Constant-Year Dollars. Dollars expressed in their value at the time of any specified year, which may, but does not have to be the base year. Also called 'constant dollars'.

3) Then-Year Dollars. Constant or base year dollars deflated or inflated through the use of indices . . . to show total money needed to buy those goods and services at the time expenditures actually are made. (35:Terms Explained and Glossary of Abbreviations)

The objective of this thesis, a cost-difference estimation, is most appropriately expressed as a cost today. Accordingly, 1992 constant-year (or base-year 1992) dollars is the time-phased method used in this thesis.

Cost Estimating Methods

Once a CBS is determined, estimates of the various cost elements are needed if a total LCC or O&S cost is to be produced.

> A cost estimate is an opinion based on analysis and judgement of the cost of a product, system, or structure. This opinion may be arrived at in either a formal or an informal manner by several methods, all of which assume that experience is a good basis for predicting the future . . . The challenge is to project from the known to the unknown by using experience with existing entities. The techniques used for cost estimating range from intuition at one extreme to detailed mathematical analysis at the other. (13:144-145)

This statement by Fabrycky and Blanchard raises several significant points.

1) Fabrycky and Blanchard were referring primarily to cost estimating as a predictor of future costs, whereas this thesis deals with cost estimation

of a current system. In this research, the reference to future costs is ignored.

2) They emphasize the relevance of the cost of other (similar) systems for estimating the cost of the system at hand.

3) Clearly, cost estimating is a mixture of art and science.

These points are also raised by others (6:14-3; 7:2-2; 8:10-2,3).

Several writers provide a description of various cost estimating methods (6:14-24 to 14-33; 7:3-21 to 3-28; 8:10-16 to 10-24; 13:144-148). Usually, the nature and amount of data will determine which method is appropriate.

1) Catalog Method. The catalog method simply involves looking for a price/cost in a catalog. This is generally the simplest method, but it obviously requires the existence of recorded cost data (6:14-29; 7:3-26; 8:10-16; 13:149-152). This research is being performed because there is no such catalog for RAAF C-130 costs.

2) Specialist Method (Expert Judgement). The specialist method simply requires a specialist (or several specialists) to give an opinion of the cost, and is of value only when such a specialist exists (6:14-32; 7:3-26; 8:10-18). The method may have relevance to this research, if a more objective and rigorous method cannot be used.

3) Man-loading Method. This is similar to the specialist method, except that the functional manager (who is not necessarily a specialist) is responsible for both estimation and implementation (6:14-31; 7:3-26; 8:10-18).

4) Parametric Method. "With this technique, the cost of an item is estimated based on a relationship with one or more other parameters" (8:10-19). For example, the cost of aircraft fuel may be calculated from the hours flown. This method has three disadvantages: the parameter chosen may not allow detailed cost breakdown; disaggregation may not be possible; an appropriate parameter may not exist. In this research, the lack of appropriate data may prevent the use of parametric estimating. In addition, unsuitability for disaggregation may prevent the isolation of differences between C-130E and C-130H models. (6:14-25 to 14-26; 7:3-21 to 3-23; 8:10-19 to 10-20; 13:159).

5) Analogy. "The technique consists of comparing one project, for which a cost estimate is desired, with another similar project which has already been completed and the costs are known" (6:14-26 to 14-28; 7:3-24 to 3-25; 8:10-21). This method seems highly relevant. The USAF has operated C-130E and C-130H aircraft for many years now, and conducts comparatively detailed cost analyses of its systems. Some disadvantages of cost estimating by analogy are:

    a) the expertise required to make appropriate adjustments for differences between the subject system and the analogous system is high (6:14-27; 13:146), and

    b) the need for detailed information about the analogous system is also high (6:14-28).

Despite these limitations, the analogous method appears to be the best method so far.

6) Grass Roots/Engineering Build-Up/Bottom-Up. "Grass roots or engineering build-up or bottom-up estimating consists of breaking a project down into all of the discrete activities, tasks, . . . and then making estimates of the labor, materials . . . and other resources required to accomplish each" (6:14-28; 7:3-25 to 3-26; 8:10-22).

7) Combination Methods (Hybrid). Often two or more standard methods may be used to suit a particular application. This is because of the limitations inherent in many of the standard methods (6:14-32,14-33; 7:3-27 to 3-28; 8:10-23).

Of these cost estimating methods, the analogous method appears to be the most suitable because it reduces the need to have data and expert cost knowledge about the RAAF C-130's. USAF C-130 aircraft are preferred for investigation because of geographical convenience and the comparatively detailed O&S costing performed routinely by the USAF.

USAF O&S Cost Models

The AF Regulation 173-13 officially addresses USAF O&S costing and describes two standard O&S cost models—CORE and SABLE. Another USDOD cost model is ABIDES. CORE (Cost-Oriented Resource Estimating) "is designed to provide a cost estimating model that MAJCOMs [major commands] may use to

develop aircraft squadron annual operating and support (O&S) cost estimates" (35:37).

SABLE is an acronym for Systematic Approach to Better Long-Range Estimating.

> The SABLE model is a variable cost model designed to estimate aircraft peacetime O&S costs for typical Air Force flying units. It was developed as a follow-on to the CORE model to provide the Air Staff with a tool to cost force structure changes quickly and accurately. The cost element structure in SABLE is very similar to that of the CORE model, and as such captures all the appropriate O&S cost categories outlined in the OSD CAIG Cost Estimating Guide. (35:43-44)

ABIDES is a model used in the USDOD budget process (33).

Compared with the CORE model, SABLE has the following features:

1) The SABLE model adds additional flexibility and output options.

2) SABLE has a sensitivity analysis capability.

3) SABLE is a then-year dollar model, whereas CORE is a constant year dollar model.

4) SABLE is not a life-cycle model.

5) SABLE includes enough cost factors, which are based upon recent historical costs, to enable the user to produce O&S cost estimates without additional data input. (33; 35:43-44)

Of these two standard cost models, SABLE has at least two advantages for the comparative analysis required in this research. First, SABLE is a cost model "designed to estimate aircraft peacetime [variable] O&S costs for [US] Air Force flying units" (33). Second, SABLE is optimized to facilitate rapid "what-if" analysis and to provide quick answers to force-structure and size questions. To this end, the model incorporates all of the cost factors needed to generate typical squadron O&S costs (33).

ABIDES is an acronym for Automated Budget Integrated Data Environment System.

> This cost model is used during the Biennial Planning, Programming, and Budgeting System (BPPBS) exercises to calculate cost categories directly associated with specific force structure (flying hours, number of primary aircraft authorized) and manpower requirements. The SABLE model uses essentially the same algorithms and inputs as the ABIDES cost model in certain categories, which are identified as ABIDES matching categories. The two models do not give exactly the same outputs, but differences are not significant and are mainly due to rounding. The ABIDES is run by the Deputy Assistant Secretary of the Air Force for Financial Management (Budget). (33)

What SABLE Actually Calculates

SABLE model output comprises:

1) "A list of cost factors used to develop the O&S cost estimates" (33).

2) "A list of Operating and Support Cost categories which show the typical O&S costs of the flying unit" (33).

Typical variable O&S costs of USAF C-130E and C-130H squadrons are shown in Appendix D, with the totals repeated in Table 2.1.

TABLE 2.1

TYPICAL VARIABLE O&S COST OF USAF C-130E AND C-130H AIRCRAFT

C-130E (US$)	C-130H (US$)	COST DIFFERENCE (US$)
60,030,00	58,330,000	1,700,000

In Table 2.1, the difference in SABLE O&S cost of USAF C-130E and C-130H aircraft squadrons is $1,700,000, which means that the C-130E costs 2.9% more than the C-130H in annual O&S costs. Comparison of the cost elements in Appendix D reveals that the bulk of the cost difference is due to higher C-130E maintenance and spares costs; while a higher C-130H fuel costs reduces the difference.

The Cost Factors that SABLE Does NOT Incorporate

In constructing SABLE, the designers omitted certain cost factors (33). This means that SABLE calculates a total O&S cost that is less than the true total. However, SABLE may still be used for the calculation of the difference in total O&S cost of two aircraft types provided that the omitted cost factors are common to both types. This is because common costs will be eliminated mathematically when the cost difference is calculated. {CORE includes some of these cost elements and therefore CORE might be a more suitable model for some purposes (35:Section 7-1).}

The following cost categories are not incorporated in the SABLE model:

1) Software maintenance/support, which may be treated as an O&S cost, is not incorporated (25:4-2). Given that the C-130E is an early generation aircraft compared to the C-130H, these costs could be significantly different for the two models. However, the C-130E/H does not contain a significant amount of equipment requiring software maintenance/support (compare with the software-driven F-18), and therefore such cost is likely to have an insignificant effect upon the total

aircraft O&S cost. Software maintenance/support will be treated as a common cost.

2) Depot non-maintenance ("the cost of personnel and material involved in non-maintenance functions at depot level") is not incorporated (33). Such cost is not likely to differ greatly among C-130 models, and can therefore be treated as a common cost.

3) Military construction (the cost of acquiring, constructing, installing, and equipping . . . public works, military installations, and facilities . . . and housing") is not incorporated (33). Such cost is likely to be independent of C-130 model, and can therefore be treated as a common cost.

4) Family housing (operation and maintenance) is not incorporated (33). Such cost is likely to be independent of C-130 model, and can therefore be treated as a common cost.

Conclusion. The O&S cost categories omitted from SABLE are likely to be common to the C-130E and C-130H, or be insignificant when compared to the total O&S cost of each aircraft model. Accordingly, this research will treat the difference in variable O&S cost as equal to the difference in total O&S cost, as calculated with SABLE for the C-130E and C-130H.

The Accuracy of SABLE Output

The accuracy of SABLE output is primarily dependent upon the accuracy of the cost factors incorporated into the model; in particular, the source and currency of

the data. In general, logistics and manpower factors are calculated from historical data that may be adjusted for past and anticipated abnormal events (such as a war). For example, systems and general support factors are based upon a one year historical record, while depot maintenance is based upon a ten year record (4). SABLE uses the following major cost factor categories: program, manpower, and logistics.

> The Primary Program Element (PPE) and the support manpower for SABLE are provided by AF/PE. These are 'typical', not squadron specific, estimates. Any manpower estimate used should be reviewed by the appropriate manpower organization. The SABLE model uses logistics factors developed by the Air Force Cost Analysis Agency, Operations and Support Division. While these factors are used to develop F&FP [Force and Financial Plan] budget requirements, they are not the specific cost factors for a specific squadron. Unit location, mission, aircraft configuration, etc impact these costs . . . Any estimate being accomplished that is specific to a unit should be reviewed by the parent MAJCOM for accuracy. (33)

SABLE uses inflation factors to convert cost elements into then-year dollars. The Air Force uses weighted inflation indices to convert constant dollars into then-year dollars. The source of these indices is the Office of the Assistant Secretary of Defense, Comptroller (35:para 5-1).

The model is kept updated as follows:

> The model is updated twice a year: In January to reflect the new inflation rates, and in the summer time-frame [about June] to reflect the updated logistics factors. In addition, updates will occur if there are major changes in the Air Force structure which would impact the squadron typical data or cost algorithms. Update data is drawn from AFR-173 tables. (33:para 2-3)

<u>Conclusion.</u> SABLE cost and inflation factors are based upon official data and are updated regularly.

The Effect on SABLE Validity of Using Squadron-Specific Cost Factors

SABLE is designed to facilitate the use of squadron-specific cost factors—to a limit (33:para 1-2b). Unfortunately, no guidance is given about the allowable degree of deviation from the typical cost factors. "If you change PAA quantity, flying hours, or the crew ratio, you will probably need to change the manpower quantities" (34).

Two things suggest that the RAAF factors used in this research are acceptable. First, the Chief of Cost Factors at the Air Force Cost Center has indicated that, in his experience, changing the PAA quantity and total flying hours from 16 to 12, and 10,192 to 9,000 respectively will not invalidate the model results (4). Second, any errors induced in manpower factors will be common to the C-130E and C-130H, and therefore will cancel when the cost difference is calculated.

Current RAAF O&S Costing

Who Does It?. The Resources Planning Branch-Air Force performs "all aspects of funds management, costing, financial accounting, associated information systems and the coordination of Air Force Budget and FYDP Programs" (2:316). Within the Resources Planning Branch, Resource Analysis-Air Force (DRA-AF) is responsible for various financial activities including "Provide a costing service, including the assessment of cost recovery rates for the use of RAAF resources" (2:316). The director of DRA-AF has indicated that:

1) RAAF costing is done for two purposes:

   a) cost recovery when aircraft are hired for commercial use/or by Govt departments,

b) changes in budget number of flying hours.

2) The last two years of actual data and the proposed expenditure in the budget are 'averaged' to give the cost per hour of aircraft operation.

3) All C-130 costs are summed to give a total cost for 18000 flying hours per year with no distinction between C-130E and C-130H. (16:3)

Flying Hour Rate Methodology. The cost recovery done by DRA-AF is based upon predetermined flying hour rates for each main aircraft type. A full description of the methodology, along with cost factors, is given in Appendix B. The significant points of this methodology are:

1) It is intended solely for cost recovery--not budgeting or cost analysis.

2) POL, spares, servicings, crew costs, and overhead costs are aggregated. In particular, C-130E and C-130H costs are aggregated (5).

3) Most costs are forecast costs based upon historical "data". In the case of spares, averaging is performed on "data" from the previous four years (9:Annex E). A Study of RAAF Aircraft Availability and Cost Factors in 1991 found that:

> Information on the financial cost of logistics resources is not managed by weapon system, but it is based rather on traditional account codes. Cost attribution is being improved under PMB [program management and budgeting] through the system of cost-center [sic] codes, but it is currently not possible to cost the separate logistics activities for each weapon system. Without this information, precise cost/availability relationships cannot be determined. However, based on information derived by DRA-AF for aircraft cost recovery purposes, some relativity of logistics costs can be established. For the four sample aircraft [which included the C-130], the main logistics costs in descending order are spares (initial and replenishment), maintenance (uniformed and contractor) and POL [petroleum, oils, and lubricants]. (9:II-III)

The study recommended that the RAAF should "develop an accurate costing system to measure the actual expenditure on the logistics functions for each weapon system" (9:II).

A Generic Life Cycle Costing Methodology

Between 29 June 1976 and 3 June 1977 the Boeing Aerospace Company, under USAF contract, performed a "historical LCC cost analysis of the Air Force C-130E aircraft" (3:1). The historical period was 15 years. The USAF had recognized that LCC estimation of future projects was being hampered by the lack of historical data for calculating LCC of current systems. Accordingly, the purpose of the research was to "identify, develop, and demonstrate a series of methods to allow for the inclusion of these variables [for which no cost data is available] in cost computations" (3).

The major limiting factor identified in the research was the lack of historical data for performing LCC analysis on an existing system. Specific problems encountered were:

1) There is no one data repository/system that provides visibility into weapon system historical cost documentation.

2) It becomes necessary first to identify all of the various repositories and then select, collect and piece together the available information for each of the specific categories and elements.

3) The predominant USAF policy of retaining historical data for only short durations (6 to 24 months) has a profound effect on the ability to collect continuous historical cost information.

4) Existing cost estimating factors must be utilized in areas where actual data are not available and with no simple method of validating the factors. (3:2-3,14)

The research report included the following general LCC methodology, which is relevant to this research into RAAF costing:

1) Identify cost categories and elements, within each life cycle phase to be considered, such as RDT&E, procurement, and operation and support costs.

2) Compare the identified cost categories and elements with the standard Air Force CACE model [an O&S cost model now superseded by CORE] to isolate those categories and elements not included.

3) Develop supplemental techniques to cover the cost categories and elements not included in the standard model.

4) Refine historical data into proper input to satisfy model equations. In addition, for the values where historical data is not available, develop estimating factors or alternate techniques to establish data value.

5) Integrate the basic CACE [CORE] model and supplemental techniques.

6) Compute the LCC estimates.

7) Analyze the LCC outputs.

8) Document the results. (3:13)

Validity

Attempting to measure or estimate something raises the question of validity. As stated by Thorndike and Hagen, and quoted from Emory: "Validity refers to the extent to which a test measures what we actually wish to measure" (12:179). Validity is of two major types—internal and external.

In this research, internal validity pertains to the use of a model for estimating O&S costs—whether USAF or RAAF.

> [Internal] Validity is the extent to which differences found with a measuring tool reflect true differences among those being tested. The difficulty in meeting this test is that usually one does not know what the true differences are; if one did, one would not do the measuring in the first place . . . How can one confirm validity without direct confirming knowledge? (12:180)

Internal validity may be classified and assessed as: content, criterion, and construct (12:180). "If the instrument contains a representative sample of the universe of subject matter of interest, then content validity is good" (12:180). Criterion validity is a question of the choice of measures for (O&S cost) estimating—have the right O&S cost elements been chosen (12:181)? Construct validity refers to the measurement of intangible or abstract characteristics, and is assumed to be not relevant to this research (12:182).

"The external validity of research findings refers to their ability to be generalized across persons, settings, and times" (12:180). Accordingly, generalizing from USAF C-130 to RAAF C-130 O&S costs raises the question of external validity. Given that the total population of USAF and RAAF C-130 aircraft is being researched, external validity must be examined by considering USAF and RAAF O&S (situational) differences. This may lead to an adjustment of USAF figures for (different) RAAF circumstances.

The Bathtub Curve Effect

The bathtub curve effect derives its name from a graph of hypothetical system failure rate plotted against system age, as previously illustrated in Figure 1.1. Assuming that the cost of unscheduled maintenance varies with the failure rate, the

effect predicts that the C-130E O&S cost will be significantly greater than that of the C-130H because of the much greater age of the C-130E. Although the effect predicts the "direction" of the cost difference, it does not predict the magnitude.

A study that contradicts the bathtub curve effect was performed by the USAF in 1984. "This study was undertaken to determine the effect of aircraft aging and usage on the cost to maintain it . . . The study concludes that there is little evidence that maintenance costs increase dramatically as an aircraft ages" (10:ii). This finding resulted from a comparison of the costs associated with maintaining old and new versions of the same aircraft. C-130, B-52, F-4, and F-15 aircraft were investigated. The finding was justified on the grounds that an aircraft is not a single component or a single system. Rather, it is a multitude of complex and interrelated components and systems that progressively wear out and are replaced. Accordingly, an aircraft is constantly being regenerated and does not suddenly reach old age. Maintenance costs do increase—but gradually—not dramatically as predicted by the bathtub curve effect (10:16).

The 1984 study may have been flawed. Of particular interest to this thesis is the comparison between the C-130E and the C-130H, which represented old and new aircraft types respectively. Table 2.2 shows the relative age of several C-130E and C-130H pairs: those of the 1984 study, the current USAF aircraft, and the current RAAF aircraft.

TABLE 2.2

RELATIVE AGE OF C-130 AIRCRAFT USED IN STUDIES

	AVERAGE C-130E AGE (years/flying hours)	AVERAGE C-130H AGE (years/flying hours)
1984 Study (10:21)	16/14,196	7/3,946
Current USAF Aircraft (17)	26.9/20,542	18.0/11,222
Current RAAF Aircraft (20)*	27/20,000	14/12,000

* Average flying hours are approximate

In Table 2.2, note that:

1) The C-130E aircraft used in the 1984 study are somewhat younger than either the current USAF or RAAF C-130E aircraft.

2) The C-130H aircraft used in the 1984 study are very much younger than either the current USAF or RAAF C-130H aircraft.

3) The current USAF and RAAF C-130E and the current USAF and RAAF C-130H aircraft are similar in age (including flying hours). (This increases the likelihood that USAF and RAAF C-130E/H aircraft will have similar maintenance needs.)

Overall, the 1984 study dealt with much younger aircraft. In particular, the "old" 1984 aircraft were not in their twilight years (the 1984 C-130E aircraft are mostly the current USAF C-130E aircraft), and therefore, not necessarily operating in the tailend

of the bathtub curve effect. A repeat of the 1984 study might now conclude that the bathtub curve effect has validity.

Some Recent RAAF C-130 Costing Research

In 1989, an AFIT student investigated the hypothesis that "Variable operating costs of RAAF and USAF C-130E Hercules aircraft can be reduced by increasing the cruise speed above the current normal speed of 280 knots" (15:5). His research required a knowledge of C-130 O&S cost. His relevant conclusions were:

> 1) RAAF C-130E Hercules cost data were analyzed and determined to be invalid.
>
> 2) RAAF C-130E and C-130H costs are aggregated and divided equally between the two aircraft types.
>
> 3) Quantifiable differences between the RAAF's C-130E and C-130H aircraft for depot servicing, contract servicing and in-house servicing have been exposed in this study. [These are:]
>
> > a) Depot servicing is scheduled for 20,260 manhours for the C-130E compared with 13,040 hours for the C-130H.
> >
> > b) The C-130E is scheduled for at least 3,500 additional manhours to complete age related repairs.
> >
> > c) The average cost of contract servicing of all C-130E aircraft since 1 July 1987 is $656,555 (AUS) per aircraft. This is more than double the $305,894 (AUS) average cost per aircraft for C-130H contract servicing over the same period.
> >
> > d) Records at the RAAF's C-130 maintenance squadron show that the C-130E requires 350 to 500 hours of overtime for each R3 servicing, compared to 100 to 150 manhours for the C-130H.
> >
> > e) A survey showed that 89.4 percent of all C-130 maintenance supervisors believe that the RAAF C-130E requires more daily flight line maintenance than the C-130H.

4) The strong conclusion is that RAAF C-130E and C-130H maintenance costs are not the same and should not be divided equally. The effect of increased cruise speeds on RAAF C-130E operating costs was therefore impossible to determine. (15:103-104)

Conclusions

The RAAF does not perform O&S costing like the USAF does. RAAF costing is used primarily for cost recovery and the data used is relatively aggregated. Much of the data needed for accurate O&S costing is simply not recorded by the RAAF. This absence of detailed data precludes the use of a simple method whereby RAAF data is collected and analyzed to produce an O&S cost.

A "traditional" USAF cost estimating method—analogy—provides a feasible basis for researching the O&S cost difference between the two RAAF C-130 types. In particular, the analogy method can be used as the basis for cost estimation. The USAF C-130E/H is an analogous system.

SABLE is currently used by the USAF for various O&S analyses, in particular what-if and comparative analysis. SABLE is a suitable model for the estimation of C-130E/H O&S cost.

An appropriate method for the estimation of the difference in RAAF C-130E and C-130H O&S cost is to:

1) Use the USAF SABLE model for C-130 O&S calculations.

2) Modify SABLE cost factors with known RAAF cost factors.

3) Calculate C-130E and C-130H O&S cost with SABLE and the modified factors.

4) Calculate the O&S cost difference.

5) Check the SABLE results with known RAAF cost elements.

III. How the O&S Cost Difference was Determined

Introduction

The objective of this research is to estimate the O&S cost difference between RAAF C-130E and C-130H Hercules aircraft. The review of O&S costing in Chapter II revealed a comparatively rudimentary RAAF C-130 O&S costing methodology and a shortage of suitable, non-aggregated RAAF data. In addition, the scope of this research precluded construction of a RAAF costing methodology from basics, and the collection of primary RAAF data. However, the review of USAF C-130 O&S costing revealed a suitable basis for an analogous RAAF C-130 costing. Available RAAF data could be used to test the validity of the analogous O&S costing. This is the basic methodology chosen to achieve the research objective.

Phase One

Phase one of the research was the literature review described in Chapter II. Resource and geographical constraints restricted the review to literature generally available within the US and Australian DOD. Phase one dealt with:

IQ1. What is O&S Cost? IQ1, "What is O&S cost?", was answered and general O&S costing concepts and methods were revealed. In particular, the components of O&S cost were identified. This provided insight into the next investigative question.

IQ2. How is O&S Cost Determined? Answering the question, "How is O&S cost determined?", led to identification of the cost factors and elements

needed to determine O&S cost, and to identification of a USAF O&S cost model—SABLE—for the estimation of RAAF C-130E/H O&S costs.

IQ3. What Data is Needed to Determine O&S Cost? Comparison of the O&S cost model elements (IQ2) with the required cost elements (IQ1), confirmed the general suitability of the identified models. Subsequently, the inputs required by the models determined the data needed for an O&S cost estimation.

IQ4. What RAAF Cost Data is Known? Identification of known RAAF cost data was necessary for selection of an appropriate costing methodology and for the RAAF O&S cost estimation validation. The ADOD supplied available RAAF cost data upon request.

IQ5. What Method is Most Suitable for Estimating RAAF C-130 O&S Cost? The USAF cost models identified in the literature review all calculated aircraft O&S cost; albeit for different purposes. The design purpose of the model tended to be the differentiating factor. The limited availability of RAAF data, the desirability of using currently available USAF data, the self-contained nature of SABLE (it comes with its own data), and SABLE's ease of use for comparative analysis made SABLE an obvious choice for this research. Accordingly, the SABLE O&S cost model became the basic method for estimating O&S cost for this research.

Phase Two

In phase two, RAAF cost factors identified in Chapter II were input to the SABLE cost model to estimate RAAF C-130E and C-130H O&S costs. These costs were then used to calculate an O&S cost difference. This provided estimates for IQ6 and IQ7:

IQ6. What is the O&S cost of RAAF C-130E and C-130H aircraft?

IQ7. What is the O&S cost difference between RAAF C-130E and C-130H aircraft?

Finally, the cost estimates were checked for validity by comparing the SABLE cost estimates with the RAAF flying hour rates (which are roughly equivalent to O&S cost elements) provided by the ADOD. This provided an answer to IQ8:

IQ8. How accurate is the calculated RAAF C-130E/H O&S cost difference?

Summary

RAAF C-130E and C-130H O&S costs were estimated using the standard USAF SABLE cost model; but with known RAAF cost data. These estimates were then used to calculate a cost difference. The SABLE estimates for RAAF C-130 aircraft were then compared with available RAAF costs to check the validity of the estimates.

IV. Determining the O&S Cost Difference

Introduction

In this section, a baseline calculation of USAF C-130E/H O&S costs was made using SABLE typical data. Next, SABLE input factors and output cost elements were modified, using known RAAF cost data, to estimate RAAF C-130E and C-130H total variable O&S costs. These individual costs were then used to estimate the operating and support cost difference between RAAF C-130E and C-130H Hercules aircraft.

SABLE

Appendix F describes how SABLE was obtained and used to perform O&S calculations in this research.

The Dollar Basis for this Research

The value of money changes over time. SABLE cost factors are developed from constant-year dollars (35:para 2-1). SABLE cost output is then converted into then-year dollars for display in the Cost Summary Report (33). Constant-year and then-year dollars are defined in Appendix A.

This research is concerned with O&S cost now. Accordingly, only the "FY92" output in the SABLE Cost Summary Report is relevant. All O&S costs in this research are therefore in FY92 US dollars (constant-year, 1992 US dollars), unless stated otherwise.

USAF C-130E/H Baseline O&S Cost Difference

The USAF C-130E/H baseline O&S cost difference was calculated in two steps:

1) Step One. In step one, SABLE was used with the model's own typical cost factors to calculate the variable O&S cost of USAF C-130E and C-130H aircraft. The SABLE output for FY92 is shown in Appendix D.

2) Step Two. In step two, the O&S cost of the C-130H was subtracted from the O&S cost of the C-130E to give the USAF C-130E/H baseline O&S cost difference.

These variable O&S costs and the cost difference are presented in Table 4.1. The table also shows the C-130E total variable O&S cost as a percentage of that of the C-130H.

TABLE 4.1

USAF C-130E/H BASELINE O&S COST DIFFERENCE (Appendix D)

USAF C-130E (US$)	USAF C-130H (US$)	COST DIFFERENCE (US$)
60,030,000	58,330,000	1,700,000 (102.9%*)

* C-130E total variable O&S cost as a percentage of that of the C-130H

Identification of Costs that are Not Common

Variable O&S costs that are not common to the C-130E and C-130H were selected from Appendix D. Costs that are not common are:

1) aviation fuel
2) depot maintenance
3) consumable supplies
4) class IV modification kits
5) class IV modification installation.

All other costs were treated as irrelevant to the estimation of the O&S cost difference between C-130E and C-130H aircraft.

Breakdown and Discussion of the Costs that are Not Common

Those costs that were found to be not common for the two C-130 models were analyzed in order to detect and isolate any common cost sub-elements. SABLE cost summary algorithms were used as the basis for analysis (33:chap 4).

Aviation Fuel. SABLE calculates the cost of aviation fuel as follows:

$$Fuel = \frac{(FH) \times (gals\ per\ FH) \times (cost\ per\ gal)}{1000000}$$

No common cost sub-elements were apparent and therefore no additional cost breakdown was performed. A difference in aviation fuel cost between the C-130E and C-130H is likely because:

1) The C-130E and C-130H are fitted with different engines, as described in Chapter II.

2) In the RAAF, the C-130H cruises at a higher speed than does the C-130E, as described in Chapter II.

Depot Maintenance. SABLE calculates the cost of depot maintenance in two parts—a flying hour portion and a PAA portion—as follows:

$$\textit{Flying hour portion} = \frac{(\textit{depot cost/FH}) \times (\textit{FH})}{1000000}$$

$$\textit{PAA portion} = \frac{(\textit{depot cost/PAA}) \times \textit{PAA} \times (\textit{depot maint inflation})}{1000000}$$

No common cost sub-elements were apparent and therefore no additional cost breakdown was performed. [Note that the PAA portion is ignored in the calculation of the true variable cost per flying hour (33:para 2-12).] The cost difference probably has two causes:

1) the C-130 model age differential, which means that more systems on the C-130E are "worn" out and need repair or replacement; and

2) a shorter mean-time-between-failure for some of the C-130E systems, which again means that more repair or replacement is required.

Consumable Supplies. SABLE calculates the cost of consumable supplies as follows:

$$\textit{Consumable supplies} = \frac{[(\textit{sys supt/FH}) + (\textit{gen supt/FH})] \times \textit{FH} \times (\textit{supt inflation})}{1000000}$$

No common cost sub-elements were apparent and therefore no additional cost breakdown was performed. The causes of a cost difference in Class IV modifications are probably the same as those for depot maintenance.

Class IV Modifications. SABLE uses a cost estimating relationship based upon flyaway cost (FAC):

$$Class\ IV\ Mod\ Kits = \frac{PAA \times 6003 \times FAC^{0.7834}\ (3010\ Inflation\ factor)}{1000000} \times 1.13$$

$$Class\ IV\ Mod\ Install = (Class\ IV\ Mod\ Kits) \times 0.15$$

No common cost sub-elements were apparent and therefore no additional cost breakdown was performed. The causes of a cost difference in Class IV modifications are probably the same as those for depot maintenance.

Conclusion. Examination of the algorithms for the costs that are not common for the C-130E and C-130H did not reveal any need for breakdown of the elements into sub-elements. Differences in the cost elements that were obtained are probably the result of the C-130E's older/different airframe and systems.

Identification of RAAF Factors

The following RAAF factors were identified for incorporation in SABLE for calculation of RAAF C-130E/H O&S costs:

1) PAA Quantity. There are 12 C-130E and 12 C-130H aircraft in the RAAF (28). This compares with the SABLE typical figure of 16.

2) Total Flying Hours. The planned rate of effort for the RAAF C-130 fleet in FY92/93 is 9000 flying hours for each C-130 model (for a total of 18000 flying hours) (5). This compares with the SABLE typical figure of 10192 hours.

3) Fuel Cost /US Gallon. The ADOD has planned upon a fuel cost of $10,425,190 for 18,000 flying hours in FY92/93 (21). These figures were converted to a cost per US gallon as follows:

$$Cost/FH = 10{,}425{,}190/18{,}000 = \$579/FH$$

$$Cost/gal = \frac{579}{(765 + 807)/2} = \$0.737/US\ gal$$

765 and 807 are the SABLE typical rates of fuel consumption, in US gal/FH, for USAF C-130E and C-130H aircraft respectively. The RAAF factor of $0.737/US gal compares with the SABLE typical figure of $0.700/US gal.

Table 4.2 lists the aforementioned RAAF factors.

TABLE 4.2

RAAF FACTORS

Factor Name	SABLE Typical Factor	RAAF Factor
PAA	16	12
Total Flying Hours	10,192	9,000
Fuel Cost/Gallon ($)	0.700	0.737

RAAF C-130E/H Estimated O&S Cost Difference

The RAAF C-130E and C-130H O&S cost difference was estimated in three steps:

1) Step One. In step one, the RAAF factors from Table 4.2 were substituted for the corresponding SABLE typical factors.

2) Step Two. In step two, SABLE was used with the model's own typical cost factors to calculate the variable O&S cost of RAAF C-130E and C-130H aircraft. These costs can be interpreted as the cost to operate and support each RAAF C-130 fleet in the US, using US cost of maintenance, spares, and personnel, but the Australian cost of fuel. The SABLE output for FY92 is shown in Appendix E.

3) Step Three. In step three, the O&S cost of the C-130H was subtracted from the O&S cost of the C-130E to give the RAAF C-130E/H estimated O&S cost difference.

These variable O&S costs and the cost difference are presented in Table 4.3. The table also shows the cost difference expressed as a percentage of the C-130H O&S cost.

TABLE 4.3

RAAF C-130E/H ESTIMATED O&S COST DIFFERENCE (Appendix E)

RAAF C-130E (US$)	RAAF C-130H (US$)	COST DIFFERENCE (US$)
56,250,000	55,010,000	1,240,000 (102.3%*)

* Cost difference expressed as a percentage of the C-130H O&S cost.

A Comparison of the SABLE Estimates with RAAF Flying Hour Costs

Appendix B contains RAAF flying hour rates (charges), which are effectively O&S cost elements that have been aggregated for the C-130E and C-130H. Table 4.4

contains the relevant costs from Appendix B, as well as the corresponding SABLE estimates from Appendix E. Note that some of the DRA-AF (Appendix B) and SABLE (Appendix E) cost estimates have been manipulated and aggregated in Table 4.4; this is to facilitate direct comparison. The paragraphs following Table 4.4 explain how the figures have been manipulated and aggregated.

TABLE 4.4

RAAF AND SABLE COST ELEMENTS COMPARED*

COST ELEMENT (taken from Appendix B)	RAAF—DRA-AF ($) (from Appendix B)	SABLE—C-130E/H ($) (from Appendix E)
POL	579	579
Spares	442	
Contract Servicing	461	
In-house Servicing	735	
Crew Cost	372 sub-total: 2,010	sub-total: 2,096

* Costs are dollars/flying hour.

<u>POL.</u> The DRA-AF and SABLE POL cost ($579) is the same. This is expected because, although the figures are derived differently, they originate from the same source—DRA-AF. The DRA-AF figure of $579 was provided directly by DRA-AF (9:Annex E). The SABLE POL (fuel) cost was based on figures in Appendix E and was calculated as follows:

$$POL/Fuel\ Cost = \frac{5{,}070{,}000 + 5{,}350{,}000}{18{,}000} = \$579/FH$$

\$5,070,000 and \$5,350,000 is the fuel cost for the C-130E and C-130H respectively.

18,000 is the combined flying hours for the C-130E and C-130H (Appendix E).

{Note that the ADOD flying hour rate summary (Appendix B) uses the term "POL" (petroleum/oils/lubricants) to describe what seems to be solely aviation fuel.

> This [POL] is derived from the FY [current] budget based on the number of flying hours and the rate of consumption of fuel per aircraft, for the previous FY. This cost is dependent on the accuracy of fuel rate and flying hours, for each aircraft type, as stated in the ACD 171. (9:Annex E)

Regardless, the total cost of fuel compared with the total cost of oils and lubricants is such as to make insignificant the cost contribution of oils and lubricants.}

RAAF Spares, Contract Servicing, In-house Servicing, and Crew Costs. RAAF servicing, parts, and personnel costs are aggregated within several charge categories. Accordingly, DRA-AF maintenance, parts, and personnel costs are aggregated in Table 4.4. The DRA-AF total charge is \$2,010.

1) Replacement Spare Parts. DRA-AF calculates replacement spare parts charges as follows:

> [Replacement spare parts costs are] Derived from the obligations from the previous four years plus the estimated obligations for the FY [current]. This figure is based upon obligation, not expenditure or actual consumption (perhaps several years after obligation/expenditure). This cost is not able to be broken down between RIs [repairable items] and consumables, nor is it able to be broken down between scheduled and unscheduled maintenance. (9:Annex E)

The DRA-AF charge for replacement spare parts is \$442 (9:Annex E).

2) Contract Servicing. DRA-AF calculates contract servicing charges as follows:

> This is based on the actual expenditure over the previous five FYs and escalated to current FY dollars by applying an escalation indice obtained from the Budget Studies and Economic Analysis Section. These expenditures are from contractors and, if known, allocated to aircraft type. If the contractor expenditure is unknown against an aircraft type, the expenditure is proportioned to all aircraft by the known expenditure ratio. This cost is not able to be broken down between RIs, engines or airframes, nor is it able to be broken down between scheduled and unscheduled servicings. (9:Annex E)

The DRA-AF charge for contract servicing is $461 (9:Annex E).

3) In-House Servicing. DRA-AF calculates contract servicing charges as follows:

> This is the cost of OLM [operational level maintenance], ILM [intermediate level maintenance] and DLM [depot level maintenance] maintenance staff for each aircraft type. This is derived from the organizational chart and includes only the technical staff used for maintenance of the aircraft type and is based on actual military salaries. This cost is not able to be broken down between RIs, engines or airframes, nor is it able to be broken down between scheduled and unscheduled maintenance. (9:Annex E)

The DRA-AF charge for in-house-servicing is $735 (9:Annex E).

4) Crew. Crew cost was included in this aggregation because DRA-AF includes maintenance personnel costs in the aforementioned DRA-AF charges, and because SABLE does not differentiate between crew and other personnel costs. DRA-AF calculates crew cost as follows:

This is the cost of operational staff at each operating squadron. This is derived from the organizational chart for each squadron and includes all aircrew and operations staff and is based on actual military salaries. (9:Annex E)

The DRA-AF charge for crew cost is $372 (9:Annex E).

5) The cost of modifications is included in capital costs, rather than the aforementioned maintenance categories (9:Annex E).

SABLE Spares, Contract Servicing, In-house Servicing, and Personnel Costs. The aggregation of the DRA-AF costs makes determination of the equivalent SABLE costs very subjective. The SABLE cost elements in Table 4.5 were averaged and then aggregated for the C-130E and C-130H, to produce an average C-130 cost of $37,720,000. The average C-130 cost of $37,720,000 is then divided by the total number of flying hours (18,000) to produce the SABLE averaged/aggregated cost of $2,096 that is entered in Table 4.4.

Comment. The closeness of the DRA-AF and SABLE costs for spares, contract servicing, in-house servicing, and personnel is surprising. However, this closeness could be coincidental. In particular, the comparative enormity of personnel costs could mask significant differences in maintenance and spares costs. Future research could attempt to isolate the personnel costs from the maintenance and spares costs. This would enable a better maintenance and spares cost comparison.

TABLE 4.5

AGGREGATION OF SABLE COST ELEMENTS FOR TABLE 4.4 (Appendix E)

COST ELEMENT	C-130E ($)	C-130H ($)	C-130 AVERAGE ($)
Depot Maintenance	4,850,000	3,430,000	
Consumable Supp.	2,140,000	1,670,000	
Depot Level Repair.	2,830,000	2,830,000	
Military Pay	27,100,000	27,100,000	
Civilian Pay	1,740,000	1,740,000	
TOTAL:	38,660,000	36,770,000	37,720,000

Conclusions

Investigative Question's 6 and 7. SABLE was used to estimate the O&S cost of RAAF C-130E and C-130H aircraft, based upon USAF typical manpower and logistics factors and Australian fuel costs (IQ 6). These estimates were then used to calculate the O&S cost difference between squadrons of RAAF C-130E and C-130H aircraft (IQ7). This produced a cost difference of $1,240,000 (the C-130E O&S cost is 2.3% more than the C-130H O&S cost) . This may be compared with the baseline USAF figures of $1,700,00 and 2.9% shown in Table 4.1.

Investigative Question 8. As a validity check, the SABLE generated O&S costs of RAAF C-130E/H aircraft (C-130E and C-130H costs after averaging) were compared with the corresponding DRA-AF costs (Flying Hour Rate Summary Charges) (IQ8); the POL costs were identical. This was expected because the costs

originated from the same source. The spares, servicing, and personnel costs were also virtually identical. This was surprising; but could be coincidental. The possible moderating influence of personnel costs makes the validity check satisfying, but inconclusive. This research also supports Green's finding that the RAAF C-130E and C-130H maintenance costs are not the same (16:104). Future research could attempt to isolate personnel costs in order to perform a better comparison.

V. Conclusions and Recommendations

Overview

This thesis estimated the O&S cost difference between RAAF C-130E and C-130H Hercules aircraft by comparing (analogous) USAF C-130E and C-130H O&S costs. The standard USAF O&S cost model SABLE was modified with known RAAF cost factors to produce estimated O&S costs for the RAAF aircraft. USAF typical manpower and logistics factors and Australian fuel costs were used. The resulting cost estimates were then used to calculate the difference in O&S cost between RAAF C-130E and C-130H aircraft.

Conclusions

The USAF SABLE O&S cost model is a feasible vehicle for some RAAF C-130 aircraft O&S cost estimations; in particular cost comparison.

If one assumes that there is no fundamental difference in RAAF and USA1F C-130E/H aircraft, operations, and support costs (RA1), then the SABLE model can provide a useful estimate of the relative O&S cost of RAAF C-130 aircraft. Although, this research did not prove that fundamental differences do not exist, the validity check did not indicate that differences do exist.

The O&S cost findings for RAAF C-130E and C-130H aircraft are summarized in Table 5.1.

TABLE 5.1

RAAF C-130E/H ESTIMATED O&S COST DIFFERENCE (Appendix E)

RAAF C-130E (US$)	RAAF C-130H (US$)	COST DIFFERENCE (US$)
56,250,000	55,010,000	1,240,000 (102.3%*)

* C-130E total variable O&S cost expressed as a percentage of that of the C-130H.

These findings suggest that the O&S cost of the C-130E is not significantly greater than that of the C-130H (additional cost is 2.3% that of the C-130H). However, no account has been taken of significant non-routine costs, such as major airframe repairs or re-engining. In addition, no account has been taken of the effect of aircraft age on operational availability or effectiveness. These items could severely distort the research findings and therefore should be considered for their possible influence in any major LCC decisions, such as to refurbish or replace an aircraft.

The relatively small range of cost data collected by the RAAF inhibits worthwhile costing and cost analysis of its C-130 aircraft. In addition, aggregation of the data that is collected reduces its value to cost analysis.

RA1, that "Differences between RAAF and USAF C-130E/H aircraft, operations, or maintenance do not invalidate the use of USAF O&S cost methods for the determination of RAAF C-130E/H O&S costs", has not been researched in this thesis and is potential research subject in itself.

RA2, that "USAF O&S costing methodology is correct" has been supported by the congruence of that methodology with other methodology, particularly as described by CAIG (25), and Fabrycky and Blanchard (13).

RA3, that "USAF O&S cost factors used in this thesis are accurate", has been supported by information from the US Air Force Cost Center, and by the general agreement between DRA-AF (Australia) and SABLE cost element estimates.

Recommendations

The RAAF should consider SABLE for possible modification and use in the calculation of RAAF C-130E/H O&S costs, as well as other costing tasks.

The RAAF should increase the number of elements for which cost data is collected and should collect less-aggregated data.

Future Research

Future research could be directed to assisting in the disaggregation of cost factors that the RAAF currently uses. This would facilitate the use of "foreign" models like SABLE for cost analysis.

Other future research concerns the measurement of aircraft effectiveness over time to determine if trends exist that might indicate the approach of the aircraft's economical life.

Appendix A: Glossary

ABIDES	"Automated Budget Integrated Data Environment System. This cost model is used during the Biennial Planning, Programming, and Budgeting System (BPPBS) exercises to calculate cost categories directly associated with specific force structure (flying hours, number of primary aircraft authorized) and manpower requirements. The SABLE model uses essentially the same algorithms and inputs as the ABIDES cost model in certain categories, which are identified as ABIDES matching categories. The two models do not give exactly the same outputs, but differences are not significant and are mainly due to rounding. The ABIDES is run by the Deputy Assistant Secretary of the Air Force for Financial Management (Budget)" (33).
Accuracy	Accuracy refers to the absence of bias. "An accurate (unbiased) sample is one in which the underestimators and the overestimators are balanced among the members of the sample. There is no systematic variance within an accurate sample" (12:243).
Actual Cost	A cost sustained in fact, as opposed to a standard, predetermined, or estimated cost.
ADOD	Australian Department of Defence.
Class IV Modification	"Retrofit changes that are required to ensure safety of personnel, systems, or equipment by eliminating operational, nuclear, or physical hazard; necessary to correct a deficiency (including one that affects reliability, maintainability, electromagnetic compatibility, or communications security); or required for logistics support purposes" (35:Terms Explained).
Common Cost	If one or more elements of cost are equal for all competing alternatives, then they are considered

	common costs and their value is irrelevant with regard to the selection of an alternative (8:7-8).
CORE	Cost Oriented Resource Estimating (a USAF O&S cost model)
Cost Estimating Relationships (CER)	A mathematical relationship between cost (the dependent variable) and one or more cost-driving independent variables (8:A-8).
Comparative Cost Estimating	Estimating a cost by comparison of the cost of the relevant item or process with the cost of other, similar items or processes (8:A-6).
Cost Element	A sub-component of the total life cycle cost of a system. For example, cost of fuel consumed is an element (sub-component) of O&S cost, which is one of the four major components of life cycle cost.
Cost Factor	"Cost factors are standard or expected costs that are used to estimate resource requirements and costs associated with (US) Air Force structures, missions, and activities" (35:para 1-2). In this research, cost factors include program, manpower, logistics, and inflation factors; as incorporated into SABLE.
Cost Model	An estimating tool consisting of one or more cost estimating relationships (CER), estimating methodologies, or estimating techniques used to predict the cost of a system or one of its lower level elements (8:A-9).
Dollars:	
base-year	Base-year dollars are "dollars expressed in their value at the time of the specified base year of a program, as if they were all expended during that year" (35:Terms Explained).
constant-year	Constant year dollars are "dollars expressed in their value at the time of any specified year, which may, but does not have to be the base year. Also called 'constant dollars'" (35:terms Explained).

then-year	Then-year dollars are "constant or base-year dollars deflated or inflated through the use of indices . . . to show total money needed to buy those goods and services at the time expenditures actually are made" (35:Terms Explained).
DRA-AF	Directorate of Resource Analysis (Australian Department of Defence).
Estimated Cost	An estimated cost is "an opinion based on analysis and judgement of the cost of a product, system, or structure" (13:144).
FH	Flying Hour.
FY	Financial/Fiscal Year.
Organic Maintenance	"Maintenance performed by the Air Force using government-owned or -controlled facilities, equipment, and military or civilian government personnel. Organic costs include civilian labor, military labor, material expense, and overhead expense" (35:para 2-1b[1]).
PAA	Primary Authorized Aircraft (e.g., the number of aircraft in the squadron).
Primary Data	Primary data is data collected from original sources especially for the task at hand (12:286).
RAAF	Royal Australian Air Force.
Relevant Cost	Those costs that are likely to be different among alternatives being considered (8:7-8).
SABLE	Systematic Approach to Better Long-Range Estimating (Model).
Secondary Data	Secondary data is data obtained by others for another purpose (12:286).
USDOD	United States Department of Defense.

Appendix B: Flying Hour Rate Summary for RAAF Aircraft

Flying hour rates are comprised of seven elements grouped into two cost levels--direct cost and full cost. Flying hour rate total cost is called full cost below.

a. Direct Cost. Direct cost comprises:

(1) POL. This is derived from the FY [current] budget based on the number of flying hours and the rate of consumption of fuel per aircraft, for the previous FY. This cost is dependent on the accuracy of fuel rate and flying hours, for each aircraft type, as stated in the ACD 171.

(2) Replacement Spare Parts. Derived from the obligations from the previous four years plus the estimated obligations for the FY [current]. This figure is based upon obligation, not expenditure or actual consumption (perhaps several years after obligation/expenditure). This cost is not able to be broken down between RIs [repairable items] and consumables, nor is it able to be broken down between scheduled and unscheduled maintenance.

(3) Contract Servicing. This is based on the actual expenditure over the previous five FY's and escalated to current FY dollars by applying an escalation indice obtained from the Budget Studies and Economic Analysis Section. These expenditures are from contractors and, if known, allocated to aircraft type. If the contractor expenditure is unknown against an aircraft type, the expenditure is proportioned to all aircraft by the known expenditure ratio. This cost is not able to be broken down between RIs, engines or airframes, nor is it able to be broken down between scheduled and unscheduled servicings.

(4) In-House Servicing. This is the cost of OLM [operational level maintenance], ILM [intermediate level maintenance] and DLM [depot level maintenance] maintenance staff for each aircraft type. This is derived from the organizational chart and includes only the technical staff used for maintenance of the aircraft type and is based on actual military salaries. This cost is not able to be broken down between RIs, engines or airframes, nor is it able to be broken down between scheduled and unscheduled maintenance.

(5) Crew Costs. This is the cost of operational staff at each operating squadron. This is derived from the organizational chart for each squadron and includes all aircrew and operations staff and is based on actual military salaries.

b. Full Cost. Full cost comprises:

(1) Direct Cost. Direct cost is the total of the aforementioned costs.

(2) Oncosts. Standard Department oncosts are applied and are equal to the sum of 15% of POL, 20% of SPARES, 5% of CONTRACT SERVICING, and the General Service Rate (GSR) and Base Support Rate (BSR) of (IN-HOUSE SERVICING + DEPOT SERVICING + CREW COSTS) for each aircraft type. Oncosts are designed to take into account all overheads associated with the operation of each aircraft type.

(3) Capital Costs. This is the sum of two costs. The first is the projected expenditure for mods for the [current] FY, which is multiplied by a factor according to the remaining life of the aircraft. This cost should include all expenditure on modifications but only non-program mods are included, with minor and major modifications not being accounted for. The second portion is the capital cost of the aircraft type, multiplied by a capital cost recovery factor according to the life of type. (9:Annex E)

Table B.1 lists the actual RAAF C-130E/H cost elements (cost per flying hour for FY90/91.

TABLE B.1

1990/91 RAAF C-130E/H COST ELEMENTS (COST/FLYING HOUR) (26)

COST CATEGORY	COST (AU$/US$)	(AU$/US$)
POL	772/579	
Spares	590/442	
Contract Servicing	614/461	
In-house Servicing	980/735	
Crew Costs	496/372	
DIRECT COST:	3452/2589	
ONCOSTS	1468/1101	
CAPITAL COSTS	765/574	
FULL COST:		5685/4264

Appendix C: O&S Cost Breakdown Structure/Cost Categories

FABRYCKY (13:29)	CAIG (25:4-2)	SABLE (33)	RAAF/DRA-AF (9:Annex E)
System/Product Life-cycle Management	Mission Personnel: • operations • maintenance • other	Manpower Factors: • drill officers • drill enlisted • civilians • active officers • active enlisted	Direct Cost: • POL • replacement spare parts • contract servicing • in-house servicing • crew costs
System/Product Operations: • system operations • operational facilities • operating personnel • energy/utilities/fuel	Unit-level Consumption: • POL/energy consumption • consumable material/repair parts • depot-level repairables • training munitions/expendable stores • other	Logistics Factors: • fuel/FH • systems support/FH • general support/FH • depot level repairables/FH • support equipment/aircraft • depot maintenance/FH • depot maintenance/aircraft • contractor logistics support/FH • contractor logistics support/aircraft	Oncosts (overhead): • 15% of POL • 20% of spares • 5% of contract servicing • a % of in-house servicing, depot servicing, and crew cost
System/Product Distribution: • marketing and sales • transportation and handling • warehousing	Intermediate Maintenance (External to Unit): • maintenance • consumable material/repair parts • other	Miscellaneous Factors (related to personnel costs and system capital costs)	Capital Costs: • a % of the projected expenditure for modifications • a % of the capital cost of the aircraft
System/Product Maintenance: • customer service • field maintenance • factory maintenance • test and support equipment • maintenance facilities upkeep	Depot Maintenance: • overhaul/rework • other		
Inventory—Spares and Material Support: • spare/repair parts • storage and handling • inventory management	Contractor Support: • interim contractor support • contractor logistics support • other		
Operator and Maintenance Training: • operator training • maintenance training • training facilities upkeep • training data	Sustaining Support: • support equipment replacement • modification kit procurement/installation • other recurring investment • sustaining engineering support • software maintenance support • simulator operations • other		
Technical Data	Indirect Support: • personnel support • installation support		
System/Product Modifications			

Appendix D: Typical Variable O&S Costs of USAF C-130E and C-130H Aircraft

	USAF C-130E	USAF C-130H
PAA Quantity	16	16
Flying Hours	10,192	10,192
Crew Ratio	1.75	1.75
Drill Officers	0	0
Drill Enlisted	0	0
Civilians	51	51
Active Officers	123	123
Active Enlisted	620	620
COST CAT.—ABIDES ($millions)		
Aviation Fuel *	5.46	5.76
Depot Maintenance *	6.08	4.11
Consumable Supplies *	2.43	1.90
Depot Level Repairables	3.20	3.20
Replacement GSE	0.66	0.66
Military Pay	27.10	27.10
Civilian Pay	1.74	1.74
TOTAL—ABIDES:	46.66	44.46
COST CAT.—OTHER ($millions)		
Installation Support—Non-Pay	4.34	4.34
PCS—Military	1.40	1.40
Training Munitions	0.46	0.46
Contractor Logistics Support	0	0
Class IV Mod. Kits *	0.76	1.20
Class IV Mod. Installation *	0.11	0.18
Medical Non-Pay	0.32	0.32
Personnel Acquisition and Training	5.96	5.96
TOTAL—OTHER:	13.37	13.87
TOTAL O&S COST ($millions)	60.03	58.33

* Elements marked with an asterisk denote costs that are not common to both C-130 models.

Appendix E: Estimated Variable O&S Costs of RAAF C-130E and C-130H Aircraft

	RAAF C-130E	RAAF C-130H
PAA Quantity	12	12
Flying Hours	9,000	9,000
Crew Ratio	1.75	1.75
Drill Officers	0	0
Drill Enlisted	0	0
Civilians	51	51
Active Officers	123	123
Active Enlisted	620	620
COST CAT.—ABIDES ($millions)		
Aviation Fuel *	5.07	5.35
Depot Maintenance *	4.85	3.43
Consumable Supplies *	2.14	1.67
Depot Level Repairables	2.83	2.83
Replacement GSE	0.50	0.50
Military Pay	27.10	27.10
Civilian Pay	1.74	1.74
TOTAL—ABIDES:	44.23	42.61
COST CAT.—OTHER ($millions)		
Installation Support—Non-Pay	4.34	4.34
PCS—Military	1.40	1.40
Training Munitions	0.35	0.35
Contractor Logistics Support	0	0
Class IV Mod. Kits *	0.57	0.90
Class IV Mod. Installation *	0.09	0.13
Medical Non-Pay	0.32	0.32
Personnel Acquisition and Training	4.95	4.95
TOTAL—OTHER:	12.02	12.39
TOTAL O&S COST ($millions)	56.25	55.01

* Elements marked with an asterisk denote costs that are not common to both C-130 models.

Appendix F: SABLE

Overview

SABLE "is a menu driven, user-friendly [computer spreadsheet] system built using Lotus 1-2-3" (33:iii). It is designed to be run on a personal computer using Microsoft (or compatible) DOS. The Air Force Cost Analysis Agency (AFCAA) is the Office of Primary Responsibility for the model. The responsible person may be reached through (703) 697-1152 (33).

The SABLE software used in this research was obtained from AFCAA through Air Force Materiel Command in June 1992. It was supplied in the form of a single, self-expanding (compressed) file, "SAB921B.EXE", dated 30 December 1992. This was the latest version at the time of the research (33).

Lotus 1-2-3 was not used in this research because it was not readily available to the author. Rather, the author's own Quattro Pro Version 4.00 was used. Running SABLE in a "foreign" spreadsheet required a special adjustment (described later) to a Quattro Pro standard setting. Thereafter, no major problems were encountered in running SABLE in Quattro Pro.

Hardware Characteristics

The author's personal computer was used for all of the SABLE analysis. It has the following significant features:

1) 80386DX 33MHz CPU

2) a hard disk with several megabytes of free space

3) 8 Mb of RAM, of which at least 1 Mb was configured as EMS (expanded) memory. (Expanded memory is essential for the program to run at an acceptable speed.)

4) an Alps Allegro 500 dot-matrix, narrow-carriage printer

Software Installation

The following steps were performed to install and run SABLE:

1) Quattro Pro Version 4.00 was installed.

2) A special hard-disk directory was created for SABLE, and the file "SAB921B.EXE" was copied to it.

3) The file "SAB921B.EXE" was executed in order to de-compress the SABLE work files.

4) Quattro Pro was started.

5) The menu item "Tools/Macro/Key Reader" was changed to "Yes", so that the Lotus macros would run successfully in Quattro Pro.

6) The Quattro Pro Print/Layout/Printer Setup String menu was modified (as described below).

7) The file "SAB921B.WK1" was retrieved into Quattro Pro.

8) The macro commands were then used, according to the self-contained SABLE menus, to operate SABLE.

Some Problems

Some problems were encountered with SABLE. These comprised errors in the SABLE Handbook documentation (33), excessive printer dependence, and an error in the macro that saves output information to a user-selected file. Specifically:

1) The depot maintenance algorithm in chapter 4 of the SABLE handbook is incorrect. The correct algorithm is:

$$Depot\ Maintenance = \frac{(depot\ cost/FH) \times (FH)}{1000000}$$

$$+ \frac{(depot\ cost/PAA) \times PAA \times (depot\ maint\ inflation)}{1000000}$$

Although this corrected algorithm can be used to manually reproduce the SABLE calculations, the absence of an inflation factor in the "depot cost/FH" component is puzzling. Further investigation (outside this research) is warranted.

2) The Class IV Modification algorithms in Chapter 4 are also incorrect. The correct algorithms are:

$$Class\ IV\ Mod\ Kits = \frac{PAA \times 6003 \times FAC^{0.7834}\ (3010\ Inflation\ factor)}{1000000} \times 1.13$$

$$Class\ IV\ Mod\ Install = (Class\ IV\ Mod\ Kits) \times 0.15$$

3) The program is excessively dependent upon the type and model of printer being used. If a wide-carriage (132 character) printer is not available or the appropriate printer escape commands are not used, then the user will have great difficulty printing the model output

satisfactorily. The following printer escape commands were needed in the Quattro Pro Print/Layout/Printer Setup String menu item:

"027@\027×0\015\027\108\015"

This string initialized the printer for each print job, set compressed print mode, and set the left margin.

4) An error in the macro that saves information to a user-selected file results in cost-factor information only—and not cost element information—being sent to the file. This is a serious inconvenience because it prevents the user from bypassing the printer limitations by "printing to a file" and then editing the file before printing via the user's regular word-processor. A temporary fix for knowledgeable computer users is to manually edit and print the output sections of the spreadsheet. However, the large size of the spreadsheet makes finding the output a time-consuming process.

None of these problems were insurmountable and all faults were reported to AFCAA.

Bibliography

1. Australian Department of Defence—Air Force. Chief of Defence Force Directive CDF 361/1989 and SEC 235/1989. Canberra ACT, Australia, 14 May 1989.

2. -----. Telephone Directory. [circa September1991]

3. Boeing Aerospace Company. Life Cycle Cost of C-130E Weapon System. Report AFHRL-TR-77-46, Seattle, July 1977.

4. Bohnke, Major R., Chief of Cost Factors. Telephone Interview. Air Force Cost Center, Alexandria VA, 02 July 1992.

5. Campbell, Colin, Director Resource Analysis. Telephone Interview. Resource Analysis-Air Force Section, Resources Planning Branch-Air Force, Canberra ACT, Australia, 05 June 1992.

6. Department of the Air Force. AFLC Cost Analysis Handbook. The Analytic Sciences Corporation (TASC). Air Force Material Command, Wright-Patterson AFB OH, 22 August 1989.

7. -----. AFSC Cost Estimating Handbook, The Analytic Sciences Corporation (TASC). Air Force Material Command, Wright-Patterson AFB OH, 11 March 1988.

8. -----. The Base Level Cost Analyst's Handbook. The Analytic Sciences Corporation (TASC), [circa July 1988].

9. Directorate of Logistics Development and Planning. A Study of RAAF Aircraft Availability and Cost Factors. DLDP AF91/7557 Pt1 (13). Australian Department of Defence, Canberra ACT, Australia, 17 September 1991.

10. Directorate of Management Sciences. The Effect of Aircraft Age and Flying Hours on Maintenance Costs. AFLC Technical Report Nr. 82-099. Wright-Patterson AFB OH, June 1984.

11. Eddins-Earles, Mary. Factors, Formulas, and Structures for Life Cycle Costing (Second Edition). Concord MA: Eddins-Earles, 1981.

12. Emory, C. William and Donald R. Cooper. Business Research Methods (Fourth Edition). Homewood IL: Irwin, 1991.

13. Fabrycky, Wolter J. and Benjamin S. Blanchard. Life-Cycle Cost and Economic Analysis. Englewood Cliffs: Prentice Hall, 1991.

14. Fletcher, Squadron Leader W.J. P-3C REFURBISHMENT—COST EFFECTIVENESS DATA. Australian Department of Defence, MATD1-AF, PRO1/4520/82/2/1 (35). Canberra ACT, Australia, 13 December 1991.

15. Green, Squadron Leader Dennis G. Reducing C-130E Hercules Operating Costs in the Royal Australian Air Force and the United States Air Force by Increasing Cruise Speeds. MS Thesis, AFIT/GLM/ENY/89S-25. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1989 [AD-A215747].

16. -----, Wing Commander Dennis G., Deputy Director Capabilities Analysis, Force Development (Air). Personal Correspondence. Department of Defence, Headquarters Australian Defence Force, Russell Offices, Canberra ACT, Australia, 14 October 1991.

17. Greenway, Major Charles R. Telephone Interview. Forces Mobility Directorate. Air Force Cost Center, Arlington VA, 23 July 1992.

18. -----. Telephone Interview. Forces Mobility Directorate. Air Force Cost Center, Arlington VA, 25 August 1992.

19. Horngren, Charles T. and George Foster. Cost Accounting—A Managerial Emphasis (Seventh Edition). Englewood Cliffs: Prentice Hall, 1991.

20. Lack, Squadron Leader Maxwell. Officer-in-charge Aircraft Maintenance Flight. Telephone Interview. No 486 Squadron, Richmond RAAF Base NSW, Australia, 02 July 1992.

21. Lindwall, Paul. Telephone Interview. Directorate of Resource Analysis-Air Force Section, Resources Planning Branch-Air Force, Canberra ACT, Australia, 05 July 1992.

22. Lockheed Aeronautical Systems Company. Hercules Cost-Effectiveness Evaluation for the Royal Australian Air Force. LG87WP6731-003, Lockheed Corporation, Marietta GA, April 1987 (Revised July 1991).

23. Meigs, Robert F. and Walter B. Meigs. Accounting: The Basis for Business Decisions (Eighth Edition). New York: McGraw-Hill Publishing Company, 1990.

24. O'Brien, Air Vice Marshall T.M., Deputy Chief of the Air Staff. Minute. Australian Department of Defence, DCAS 409/91 AF 91-2361 Ptl (10). Canberra ACT, Australia, 8 May 91.

25. Office of the Secretary of Defense, Cost Analysis Improvement Group. Aircraft Operating and Support Cost Development Guide. Guide. Washington DC, May 1992.

26. Pappas, Flight Lieutenant Paul. Personal Correspondence. Australian Department of Defence, Capabilities Analysis 3, Director Systems Analysis (Air), Canberra ACT, Australia, 19 November 1991.

27. -----. Personal Correspondence. Australian Department of Defence, Capabilities Analysis 3, Director Systems Analysis (Air), Canberra ACT, Australia, 9 April 1992.

28. Roediger, Wing Commander T.A., Commanding Officer. Telephone Interview. No 486 Squadron, Richmond RAAF Base, NSW Australia, 02 July 1992.

29. Royal Australian Air Force. C-130 Hercules Standard Operating Procedures. Volume 1. Richmond NSW, Australia: HQALG, 1991.

30. -----. Flight Manual C-130E. DI(AF)AAP7211.012-1. Penrith NSW, Australia: Air Headquarters, 01 March 1984.

31. -----. Flight Manual C-130H. DI(AF)AAP7211.017-1. Penrith NSW, Australia: Air Headquarters, 01 May 1978.

32. Tidd, Air Commodore D.A., Director General Logistics—Air Force. AIR 5216--C-130E Replacement/Refurbishment. Australian Department of Defence, DGLOG-AF 337/1990 AF85/44164 Ptl (39). Canberra ACT, Australia, 13 August 1990.

33. United States Department of the Air Force. Systematic Approach to Better Long-Range Estimating (SABLE) Model—Version 92-1C [handbook]. Air Force Cost Center, Arlington VA, December 1991.

34. -----. Systematic Approach to Better Long-Range Estimating (SABLE) Model—Version 92-1C [software]. Air Force Cost Center, Arlington VA, December 1991.

35. -----. USAF Cost and Planning Factors. AFR 173-13. Washington: HQUSAF, 13 February 1991.

Vita

Squadron Leader Terry Sidey was born on 26 August 1955 in Brisbane, New South Wales, Australia. He grew up on the Gold Coast, near Brisbane, and completed high school at Aquinas College in 1972. He then joined the Royal Australian Air Force (RAAF) and spent four years at the RAAF Academy. In 1976, he graduated and was commissioned as a Flying Officer. His study at the Academy and the nearby University of Melbourne was recognized by the award of a Bachelor of Science (Physics) degree and a Graduate Diploma in Military Aviation. In 1977, he successfully completed pilot training and received his wings.

Squadron Leader Sidey's flying career has spanned fifteen years. During that time, he has logged about 5,500 flying hours, including about 2,000 hours as a flying instructor. The majority of his flying has been associated with the C-130E, the C-130H, and the Macchi (a single-engine jet trainer). Squadron Leader Sidey's most recent flying assignment was as the Training Flight Commander at No 36 Squadron RAAF, flying the C-130H.

In 1991, Squadron Leader Sidey commenced a Master of Science degree, majoring in logistics, at the US Air Force Institute of Technology. After graduation, he returns to the Department of Defence (Air Force) in Canberra, Australia.

Permanent Address: 45 William Cox Drive
Richmond
NSW 2753 Australia

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1992	Master's Thesis

4. TITLE AND SUBTITLE
ESTIMATING THE OPERATING AND SUPPORT COST DIFFERENCE BETWEEN ROYAL AUSTRALIAN AIR FORCE C-130E AND C-130H HERCULES AIRCRAFT

5. FUNDING NUMBERS

6. AUTHOR(S)
Terry J. Sidey, Squadron Leader, RAAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology, WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GLM/LSQ/92S-40

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This research investigated the operating and support cost (O&S cost) of Royal Australian Air Force (RAAF) C-130E and C-130H aircraft. The purpose was twofold--provide information about the relative O&S cost of the RAAF's old and "new" C-130 aircraft; and increase knowledge and understanding of aircraft O&S costing within the RAAF.

Preliminary research indicated that RAAF O&S costing was rudimentary and that suitable RAAF O&S data would be difficult to obtain. Accordingly, an analogous O&S cost system--the USAF SABLE cost model and USAF C-130E/H aircraft--was used to estimate the RAAF C-130E/H cost difference. The foundation for this research is that RAAF and USAF C-130E/H aircraft, operations, and overall maintenance costs are not significantly different.

Based upon analogous costs of USAF C-130E and C-130H aircraft calculated using the SABLE model, this research concluded that the RAAF C-130E O&S cost is only about 2.3% greater than that of the RAAF C-130H. This accords with current, limited RAAF costing information and an earlier USAF study of increasing maintenance cost as an aircraft ages.

14. SUBJECT TERMS
Cost Estimates, Cost Models, Costs, Aircraft, Theses, Cost Analysis, Cost Effectiveness

15. NUMBER OF PAGES
92

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

AFIT Control Number AFIT/GLM/LSQ/92S-40

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/LSC, Wright-Patterson AFB OH 45433-9905.

1. Did this research contribute to a current research project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Please estimate what this research would have cost in terms of manpower and/or dollars if it had been accomplished under contract or if it had been done in-house.

   Man Years ______________ $ ______________

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3, above) what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments

______________________ ______________________

Name and Grade Organization

______________________ ______________________

Position or Title Address

PARTMENT OF THE AIR FORCE
IT/LSC Bldg 642
i0 P St
i33-7765

OFFICIAL BUSINESS

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS MAIL PERMIT NO. 1006 DAYTON OH

POSTAGE WILL BE PAID BY U.S. ADDRESSEE

Wright-Patterson Air Force Base

AFIT/LSC Bldg 642
2950 P St
Wright Patterson AFB OH 45433-9905